CHAPTER 3

METHODOLOGY

3.1 OVERVIEW

This chapter consists of research methodology for the heat transfer evaluation with TiO_2 and SiO_2 nanofluids in a tube with twisted tape. The aim of the chapter is to explain the nanofluid preparation, the stability of nanofluids, the methods of properties measurement, the design and instrumentation of the experimental setup, and the formulation of mathematical model. The chapter presents the steps of nanofluid preparation by the dilution technique. The stability testing is important to show the state of dispersion of suspended nanoparticles in the base of water. The testing includes the visual condition observation, pH measurement, electrical conductivity measurement and transmission electron microscopy (TEM). The methods of properties measurement for thermal conductivity and viscosity are presented in the chapter, whereas the density and specific heat of nanofluids are estimated using mixture relation. The experimental setup is designed and fabricated for flow of fluid in a tube with twisted tape. The functions of the various components are explained item wise. Finally, the chapter provides a detailed mathematical model formulation of the eddy diffusivity equation for application with nanofluid turbulent flow over twisted tape. The equation is applicable as the nanofluids considered in the range of concentration are assumed homogenous.

3.2 PREPARATION OF NANOFLUIDS

The nanofluids can be prepared by two different methods. The first approach is a one step process. The nanoparticles are synthesized and simultaneously dispersed in a base fluid. The process is done in one single step. It is recommended to prepare nanofluids with one step process for high thermal conductivity of metal particles in order to avoid oxidation effect. The second approach of nanofluid preparation is by the two step process. The nanofluids are prepared in two stages. The nanoparticles are produced in the form of powder in the first step. Then, the nanoparticle is dispersed to the base liquid to form a stable solution called nanofluids. However, the challenge of this approach is overcoming the agglomeration and stability of prepared nanofluids. The agglomeration of the particle will cause the nanoparticle to settle down faster.

TiO_2 and SiO_2 water based nanofluids were used in the present heat transfer analysis. It was commercially produced by US Research Nanomaterials, Inc for research purposes in the form of liquid suspension. The procured TiO_2 and SiO_2 nanofluids were prepared to a new concentration by dilution techniques. The technique was applied successfully by the previous researchers in their heat transfer evaluation for TiO_2 and SiO_2 nanofluids (Bontemps et al., 2008; Duangthongsuk and Wongwises, 2010 and Ferrouillat et al., 2011).

The procured nanofluids in Table 3.1 are available in weight percent concentration, ω. SiO_2 nanofluid with 99.99 % purity contains nanoparticles with average diameter of 22 nm. It was supplied with original concentration of 25 % weight concentration. TiO_2 nanofluid with 99 % purity consumes TiO_2 nanoparticles with the diameter of 50 nm and original weight concentration of 40 %. The initial pH of TiO_2 and SiO_2 nanofluids were 6.5 and 11, respectively. The basic expressions for concentration of nanofluids by volume percent, ϕ and weight percent, ω are represented by Eqs. (3.1) and (3.2), respectively. The nanofluids in weight concentration, ω is converted to volume concentration, ϕ using Eq. (3.3). The new expression in Eq. (3.3) was derived by Eqs. (3.1) and (3.2). The previously published literatures for nanoparticle properties are given in Table 3.2.

$$\omega = \frac{m_p}{m_p + m_w} \times 100 \tag{3.1}$$

$$\phi = \left(\frac{m_p}{\rho_p}\right) \Big/ \left(\frac{m_p}{\rho_p} + \frac{m_w}{\rho_w}\right) \times 100 \tag{3.2}$$

$$\phi = \frac{\omega \rho_w}{\frac{\omega}{100}\rho_w + \left(1 - \frac{\omega}{100}\right)\rho_p} \tag{3.3}$$

Table 3.1: Properties of nanofluids supplied by US Research Nanomaterials, Inc

Type of nanofluid	**Diameter, (nm)**	**Weight concentration, ω (%)**	**Volume concentration, ϕ (%)**
TiO_2	50	40	13.62
SiO_2	22	25	13.06

Table 3.2: Physical properties of metal and metal oxide nanomaterials

Nanoparticle	**Thermal Conductivity, W/m.K**	**Density, kg/m^3**	**Specific heat, J/ kg.K**	**References**
Al_2O_3	36	3880	773	Pak and Cho (1998)
Cu	383	8954	386	Kothandaraman and Subramanyam (2007)
CuO	69	6350	535	Fotukian and Nasr Esfahany (2010)
Fe_3O_4	80.4	5180	670	Sundar et al. (2012)
SiC	490	3160	675	Kothandaraman and Subramanyam (2007)
SiO_2	1.4	2220	745	Vajjha et al. (2010)
TiO_2	8.4	4175	692	Pak and Cho (1998)
ZnO	29	5600	514	Vajjha and Das (2009), Hong et al. (2007)
ZrO_2	1.7	5500	502	Kothandaraman and Subramanyam (2007)